(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 470 309 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **90308750.0**

(51) Int. Cl.5: **E21D 9/06**

(22) Date of filing: **09.08.90**

(43) Date of publication of application:
12.02.92 Bulletin 92/07

(84) Designated Contracting States:
AT DE FR GB

(71) Applicant: **ISHIKAWAJIMA-HARIMA JUKOGYO KABUSHIKI KAISHA**
2-1, Ote-machi 2-chome
Chiyoda-ku Tokyo 100(JP)

Applicant: **SATO KOGYO Co., Ltd.**
1-11, Sakuragi-cho
Toyama-shi, Toyama-ken 930(JP)

Applicant: **TOKYO Keiki CO., Ltd.**
16-46, Minamikamata 2-chome, Ota-ku
Tokyo-to 144(JP)

(72) Inventor: **Kiritani, Yoshiharu**
No. 33-8, Harayama 2-chome
Urawa-shi, Saitama-ken 336(JP)
Inventor: **Onishi, Yutaka, Ichigaoryo Sato Kogyo Co.Ltd.**
No.1-1, Edakita 2-chome, Midori-ku
Yokohama-shi, Kanagawa-ken 227(JP)
Inventor: **Tagata, Shigeyoshi**
No.1-18, Ima-Machi
Okagi-shi, Gifu-ken 503(JP)
Inventor: **Umeno, Koichi**
No.2-5-5-, Tamagawa
Ota-ku, Tokyo-to 146(JP)

(74) Representative: **Jennings, Nigel Robin et al**
KILBURN & STRODE 30 John Street
London WC1N 2DD(GB)

(54) Method and apparatus for controlling the attitude of a shield excavator.

(57) A shield excavator including a plurality of thrust jacks (10a, 10b) distributed around its periphery is caused to advance over a predetermined curved path by the application of a rotational moment to it by dividing the thrust jacks into two groups of mutually adjacent jacks and applying a load pressure to the thrust jacks of one group and a lower controlled pressure to the thrust jacks of the other group. The positions at which the thrust jacks are divided into the two groups are selected in dependence on the direction of the curved path which the excavator is to follow. The controlled pressure is applied to that group of thrust jacks which is on the inside of the curved path which the excavator is to follow. The magnitude of the controlled pressure is controlled in dependence on the magnitude of the rotational moment which is to be applied to the excavator.

EP 0 470 309 A1

The present invention relates to a method and an apparatus for controlling the attitude of a shield excavator to excavate a curved tunnel or to change the direction of advance of the excavator.

A shield excavator includes a plurality of thrust jacks distributed around a shield frame to advance the excavator. Advancement of the excavator is effected by extending the piston rods of the jacks by supplying pressurized working oil to the jacks whilst their rear ends are securely supported by the segments of the excavator.

In order to advance the excavator over a curved path, some of the jacks are supplied with sufficient pressurized working oil to extend their piston rods while the remaining jacks are supplied with no working oil or supplied with working oil pressurized only to the extent that no thrust force is imparted to the excavator. Thus the remaining jacks perform only a no-load following operation such that their piston rods advance or extend merely to follow the advance of the excavator. It will be appreciated that it may be desired to advance the excavator over a curved path, i.e. change its direction movement, either because the tunnel is to be curved at that point or because the tunnel is supposed to be straight at that point and the excavator has deviated from its intended path.

Fig. 1 shows the hydraulic circuit of a conventional automatic directional control system for use with a conventional shield excavator. A hydraulic pump 2, which pumps oil from a storage tank 1 and pressurizes it, is connected at its discharge port to one end of a pipeline 3, the other end of which is connected to a main selector valve 4. The valve 4 is connected through a return pipeline 5 to the tank 1 so as to return the working oil.

The valve 4 is further connected to two pipelines 6 and 11. The pipeline 6 branches into two pipelines 7a and 7b which respectively communicate with the head-side oil chambers 22a and 22b of thrust jacks 10a and 10b through jack load pressure selector valves 8a and 8b and pipelines 9a and 9b. The pipeline 11 branches into two pipelines 12a and 12b which respectively communicate with the rod-side oil chambers 23a and 23b of the jacks 10a and 10b.

A no-load following valve block 13 comprises a pressure reducing valve 15 for reducing the pressure of the working oil from a selector valve 14, a pipeline 16 for the passage of the working oil from the reducing valve 15 and check valves 17a and 17b for preventing the working oil from returning to the valve 15. The pipeline 6 is connected to the selector valve 14 though a pipeline 18. The check valves 17a and 17b are connected to the pipelines 9a and 9b through pipelines 19a and 19b.

Pipelines 19a and 19b are connected to the pipelines 9a and 9b, respectively, and to the tank 1 through a pipeline 20 and respective check valves 21a and 21b. Reference numerals 24 and 25 denote safety valves. It is to be understood that in practice many thrust jacks 10 are disposed side by side though only two jacks 10a and 10b are shown in Fig. 1. Set pressures P1, P2 and P3 of the safety valves 24 and 25 and the pressure reducing valve 15, respectively, are adjusted to satisfy the following condition:

$$P1 \fallingdotseq P2 \gg P3$$

Fig. 2 illustrates a typical operation control board 26 of a conventional shield excavator. The board 26 comprises a plurality of equiangularly spaced jack selection switches 27 (12 switches are shown), which are disposed in the form of ring corresponding to the thrust jacks, rotational moment directional pilot plates 28 (24 pilot plates are shown), disposed in positions corresponding to the switches 27 and midway between the switches 27, and a jack operation unit 32 comprising push, pull and stop switches 29, 30 and 31. The board 26 further has a load pressure indicator 33, a left jack stroke meter 34, a right jack stroke meter 35 and a pitching indicator 36 (or inclinometer in the axial direction).

When a selection switch 27 is pushed, the switch 27 lights up and correspondingly a command signal is outputted to a valve unit 37 so as to change over the associated selector valve 8a, 8b of the corresponding jack 10a, 10b to the load pressure side. When the push switch 29 is pushed, the switch 29 lights up and correspondingly a command signal is outputted to the valve unit 37 so as to change over the main selector valve 4 to the push side, whereby the piston rods of the selector valves 8a 8b having been changed over to the load pressure side are extended in unison for excavation. When the switches 27 and 29 are pushed again, their light goes off and the respective selector valves 8a, 8b and 4 are changed over to neutral positions (or closing sides).

When the shield excavator is to be advanced in a straight line, all the jack selection switches 27 are pushed on so that all the selector valves 8a and 8b are changed over to the load pressure sides. Then the push switch is actuated so that the main selector valve 4 is changed over to the push side. As a result, all the jacks 10a and 10b are simultaneously extended to advance the excavator straight ahead for excavation.

When excavation of a curved tunnel or correction in the direction of advance of the shield excavator is required, the operator turns off those of the jack selection switches 27 which correspond to the jacks on the inside of the bend through which the excavator is to move. As a result, the corresponding selector valves 8a and 8b are changed over to their neutral positions so that the corresponding jacks 10a and 10b are de-energized and consequently a rotational moment is imparted to the excavator.

Whether or not the desired attitude has been attained is checked by the left and right jack stroke meters 34 and 45 as regards the left and right directions and by the pitching meter 36 as regards the upward and downward directions. When the excavator is inclined too much or too little in the upward or downward direction and/or in the right or left direction, such deviation is compensated by correspondingly increasing or decreasing the number of jacks which are energized.

Which jacks are to be energized is determined as follows: From a total thrust required to advance the excavator, a required minimum number of thrust jacks (in general more than half of all the thrust jacks) is determined. The thrust jacks to be energized are selected in a jack pattern or arrangement such that the required rotational moment is obtained with a number of thrust jacks which is greater than the minimum number and as high as possible, the selected jacks being in a dispersed pattern so as not to locally over-load the segments.

In this known system, the number of jacks to be energized is determined depending upon the required total thrust; and the jacks to be energized are selected in accordance with experience having regard to their combined vertical and horizontal moments. In order to minimise meandering movements of the excavator and to attain a high degree of accuracy of the finished tunnel, any positional error and attitudinal deviation of the shield excavator must be compensated for as soon as possible. Therefore, the rotational moment must be changed gradually, which requires the jack selection to be effected in a complex, dispersed and nearly random pattern. The jack selection is conventionally effected in accordance with the operator's personal judgement and is very difficult and requires a skilled operator.

In a further known system, gyroscopic or laser-type automatic position and attitude sensors are provided. In response to signals from the sensors, the thrust jacks are controlled to effect automatic direction control of a shield excavator. In this case also, the jack patterns or combinations to be selected are so numerous that the algorithm for selecting the jacks to be energized is extremely complicated.

Accordingly, it is an object of the present invention to provide a method and apparatus for controlling or correcting the attitude of a shield excavator which is both simple and can operate automatically and which can be operated by an ordinary unskilled operator because the number of steps which require judgement and experience by the operator are minimised.

According to the present invention a method of controlling the attitude of a shield excavator including a plurality of thrust jacks distributed around the excavator of the type including applying a rotational moment to the excavator to cause it to advance over a curved path by dividing the thrust jacks into two groups, applying a load pressure to the thrust jacks of one group and a lower pressure to the thrust jacks of the other group is characterised in that the thrust jacks of each group are mutually adjacent, that the positions at which the thrust jacks are divided into the two groups are selected in dependence on the direction of the curved path which the excavator is to follow, that the reduced pressure is applied to that group of thrust jacks which is on the inside of the curved path which the excavator is to follow and that the reduced pressure is a controlled pressure whose magnitude is controlled in dependence on the magnitude of the rotational moment which is to be applied to the excavator.

The present invention also embraces an apparatus for carrying out such a method of the type including a plurality of jack load pressure selector valves associated with a respective thrust jack, a main selector valve arranged to direct a pressurised hydraulic fluid from a hydraulic pump selectively to one side of the pistons of the thrust jacks or via the jack load pressure selector valves to the other side of the pistons of the thrust jacks, a pressure reducing valve connected to the hydraulic pump and pipelines which are connected to the outlet of the pressure reducing valve and to the said other side of the piston of a respective thrust jack and is characterised in that the pressure reducing valve is of controlled type whereby its output pressure is variable, that a controlled pressure selector valve is provided in each pipeline which is interlocked with the associated load pressure selector valve such that when one is open the other is closed, that an input device is provided for setting the direction of the rotational moment to be applied to the excavator, that a controller is provided for controlling the change-over of the interlocked pressure selector valves and load pressure selector valves on receipt of a command signal from the input device and that a variable setting device is provided for varying the controlled pressure of the pressure reducing valve in dependence on the desired magnitude of the rotational moment.

Thus in the method and apparatus of the present invention, the direction in which the shield excavator is to be moved is set by an input device whereby the jack load pressure selector valves and controlled pressure selector valves are automatically changed over in dependence on the input direction so as to divide the thrust jacks into groups to which load pressure and controlled pressure, respectively, are applied. Furthermore the magnitude of the required rotational moment is determined by a variable setting device such as a potentiometer so that the controlled pressure is set automatically.

Further features and details of the invention will be apparent from the following description of one specific enbodiment which is given by way of example with reference to figures 3 to 5 of the accompanying drawings, in which:-

Fig. 3 is a hydraulic circuit diagram of a preferred embodiment of the present invention;

Fig. 4 is a block diagram of the operation control board thereof; and

Fig. 5(a), 5(B) and 5(C) illustrate three different examples of the way in which the thrust jacks can be divided into groups.

Similar reference numerals are used to designate similar parts throughout the figures.

Fig. 3 shows a preferred embodiment of the invention in which a controlled pressure supply circuit 38 is provided instead of the conventional no-load following valve block 13 shown in Fig. 1.

The pipeline 6, which supplies the working oil from the tank 1 through the hydraulic pump 2, the pipeline 3, the main selector valve 4, the pipelines 5, 7a and 7b, the selector valves 8a and 8b and the pipelines 9a and 9b to the head-side oil chambers 22a and 22b of the thrust jacks 10a and 10b, is connected through a steplessly pressure-controllable electro-hydraulic pressure reducing valve 40 to controlled pressure selector valves 41a and 41b. Pipelines 42a and 42b from the valves 41a and 41b are connected to the head-side pipelines 9a and 9b of the corresponding thrust jacks 10a and 10b.

The jack load pressure selector valves 8a and 8b and the controlled pressure selector valves 41a and 41b are paired in conjunction with the jacks 10a and 10b and are so interlocked that when one is opened, the other is closed.

Between the discharge side of the valve 40 and the pipeline 5 is a pipeline 44 with a safety valve 43. The set pressure of the safety valve 43, which is higher than that of the pressure reducing valve 40, is equal to the set pressure of the safety valve 24 or is correlated with the set pressure of the valve 40 by use of an electro-hydraulic valve. Reference numeral 45 represents a load pressure sensor; and 46, and controlled pressure sensor.

Fig. 4 illustrates the operation control board 47 used in the present invention. An input device 49 serves to digitally command a desired direction of rotational moment to be applied to the excavator to an arithmetic controller 48 incorporated in the board 47. In response to the output 50 from the controller 48, the jack load pressure selector valves 8a and 8b, the controlled pressure selector valves 41a and 41b and the main selector valve 4 are switched.

In the arithmetic controller 48, the number of thrust jacks to be energized is determined in response to a signal 53 commanding the direction of the rotational moment from the input device 49 or in response to a separate set signal representative of the number of thrust jacks to be energized. A signal 55 from a variable setting device or potentiometer 54 for setting the magnitude of the rotational moment is adjusted depending upon the determined number of the thrust jacks to be energized. A signal 57 consisting of the thus adjusted signal 56 added to a load pressure feedback signal 60 is inputted into a control amplifier 58, the output of which in turn is applied to the pressure reducing valve 40.

Reference numeral 59 represents a controlled pressure indicator for indicating the controlled pressure detected by the sensor 46. The controlled pressure indicator 59 is disposed adjacent to the load pressure indicator 33 which indicates the load pressure detected by the sensor 45.

When advancing the shield excavator, the number on the rotational moment directional pilot plate 28 indicating the direction in which the excavator is to be directed or oriented is digitally inputted to the input device 49.

Then, in response to said desired direction of the rotational moment, the load pressure selector valves 8a and 8b and the controlled pressure selector valves 41a and 41b are switched over to communicate with the corresponding thrust jacks 10a and 10b. The magnitude of the desired rotational moment is set by the variable setting device or potentiometer 54 so that the required controlled pressure of the electro-hyraulic pressure reducing valve 40 is set, whereby the rotational moment with the desired direction and with the desired magnitude is obtained.

In order to amend the direction and magnitude of the rotational moment, any variation in attitude of the shield excavator is monitored based on the displays of the right and left jack stroke meters 34 and 35 and the pitching meter 36 and the magnitude of the rotational moment obtained from the difference in display between the load pressure indicator 33 and the controlled pressure indicator 59 and the number of the energized jacks and the input device 49 and the potentiometer 54 are adjusted accordingly to attain a desired attitude.

Fig. 5(A) illustrates the excavation of a curved tunnel with a total of 12 thrust jacks. Jacks 1 - 6 are assigned to the load side while the remaining six jacks 7 - 12 are assigned to the controlled pressure side. The direction of rotational moment is oriented to 18.

Fig. 5(B) illustrates a change of the direction of the rotational moment from 18 to 20. In this case, the jack 1 is energized by the controlled pressure while 7 is in load operation.

When a direction of the rotational moment oriented to 19 is selected as shown in Fig. 5(C), as compared with the state shown in Fig. 5(A), one jack 7 is added to the load pressure operation. In this case, in order to prevent any variations in the magnitude of the rotational moment, the electro-hydraulic pressure reducing valve 40 is adjusted in accordance with the calculation by the arithmetic controller 48.

By using the above-described operation, the direction of the rotational moment can be set and adjusted by half the pitch of the thrust jacks 10a and 10b.

Thus, in general, the line along which the thrust jacks are divided into two groups extends perpendicular to the direction of the curve along which the excavator is to move. If, as is preferred, the number of jacks is even and the number of directions in which the excavator may be moved is twice the number of jacks, then if the direction number is even the number of jacks to which load pressure is applied is one half the total number and if the direction number is odd the number of jacks to which load pressure is applied is one half the total number plus 1, i.e. 7 if there is a total of 12 jacks.

The positions at which the jacks are divided into two groups, in the event that there are 12 jacks, are determined as follows. If the direction number D is even then B' is calculated from the formula $B' = D/4 + 4$. If $B' \geqq 13$ then B is calculated from the formula $B = B'-12$. If $B < 13$ then $B = B'$. Starting from jack No.B, six jacks in the clockwise direction are subjected to load pressure. If D is odd, then B' is calculated from the formula $B' = (D + 1)/2 + 3$. If $B' \geqq 13$, then $B = B'-12$. If $B' < 13$, then $B = B'$. Starting from jack No.B, seven jacks in the clockwise direction are subjected to load pressure. In all cases the controlled pressure is applied to those jacks to which load pressure is not applied. It will be readily understood how the above calculations may be altered for different numbers of jacks and directions of movement.

It will be understood that the method and apparatus for controlling the attitude of the shield excavator according to the present invention is not limited to the above-described embodiment and that various modifications may be effected.

The method and apparatus for controlling the attitude of the shield excavator of the present invention have the following advantage:

(i) The attitude of the shield excavator can be controlled only by setting the direction and magnitude of the rotational moment and a skilled operator is not necessary.

(ii) The thrust jacks are divided into two groups of mutually adjacent thrust jacks, one of the groups being controlled by the load pressure while the other group is controlled by the controlled pressure. As a result, the control of the attitude of the shield excavator is simplified and effected automatically.

Claims

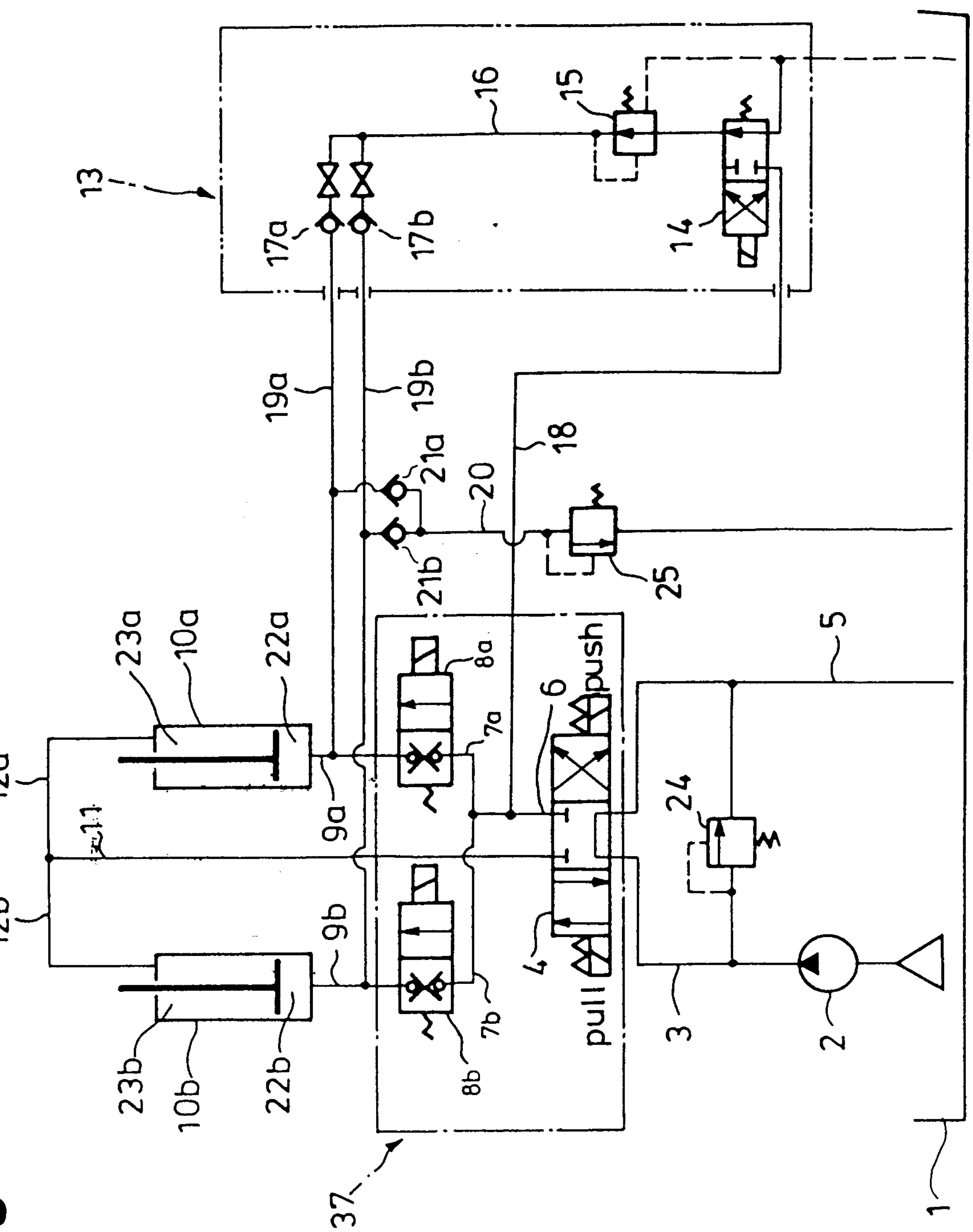
1. A method of controlling the attitude of a shield excavator including a plurality of thrust jacks distributed around the excavator, the method including applying a rotational moment to the excavator to cause it to advance over a curved path by dividing the thrust jacks into two groups, applying a load pressure to the thrust jacks of one group and a lower pressure to the thrust jacks of the other group, characterised in that the thrust jacks (10a, 10b) of each group are mutually adjacent, that the positions at which the thrust jacks are divided into the two groups are selected in dependence on the direction of the curved path which the excavator is to follow, that the reduced pressure is applied to that group of thrust jacks which is on the inside of the curved path which the excavator is to follow and that the reduced pressure is a controlled pressure whose magnitude is controlled in dependence in the magnitude of the rotational moment which is to be applied to the excavator.

2. Apparatus for controlling the attitude of a shield excavator of a type including a plurality of thrust jacks (10a, 10b) distributed around it and for controlling the application of a rotational moment to the excavator to cause it to advance over a curved path, the apparatus including a plurality of jack load pressure selector valves (8a, 8b) associated with a respective thrust jack, a main selector valve (4) arranged to direct a pressurised hydraulic fluid from a hydraulic pump (2) selectively to one side (23a, 23b) of the pistons of the thrust jacks or via the jack load pressure selector valves (8a, 8b) to the other side (22a, 22b) of the pistons of the thrust jacks, a pressure reducing valve (40) connected to the hydraulic pump (2) and pipelines (42a, 42b) which are connected to the outlet of the pressure reducing valve (40) and to the said other side (22a, 22b) of the piston of a respective thrust jack, characterised in that the pressure reducing valve (40) is of controlled type whereby its output pressure is variable, that a controlled

pressure selector valve (41a, 41b) is provided in each pipeline (42a, 42b) which is interlocked with the associated load pressure selector valve (8a, 8b) such that when one is open the other is closed, that an input device (49) is provided for setting the direction of the rotational moment to be applied to the excavator, that a controller (48) is provided for controlling the change-over of the interlocked pressure selector valve (41a, 41b) and load pressure selector valves (8a, 8b) receipt seat of a command signal (53) from the input device (49) and that a variable setting device (54) is provided for varying the controlled pressure of the pressure reducing valve (40) in dependence on the desired magnitude of the rotational moment.

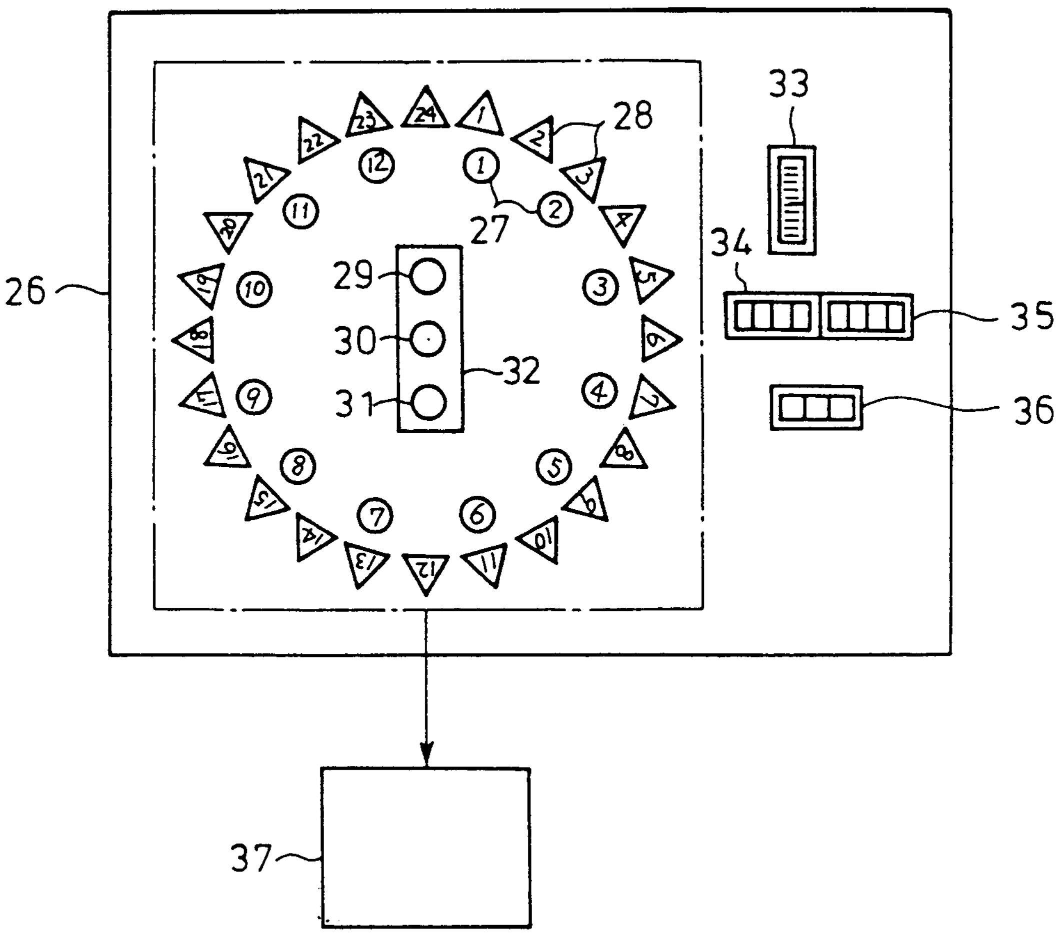
3. Apparatus as claimed in Claim 2, characterised in that it is arranged to apply load pressure to a first group of mutually adjacent thrust jacks and controlled pressure to a second group of mutually adjacent thrust jacks and to divide the thrust jacks into the two said groups in dependence on the direction of the rotational moment to be applied to the excavator.

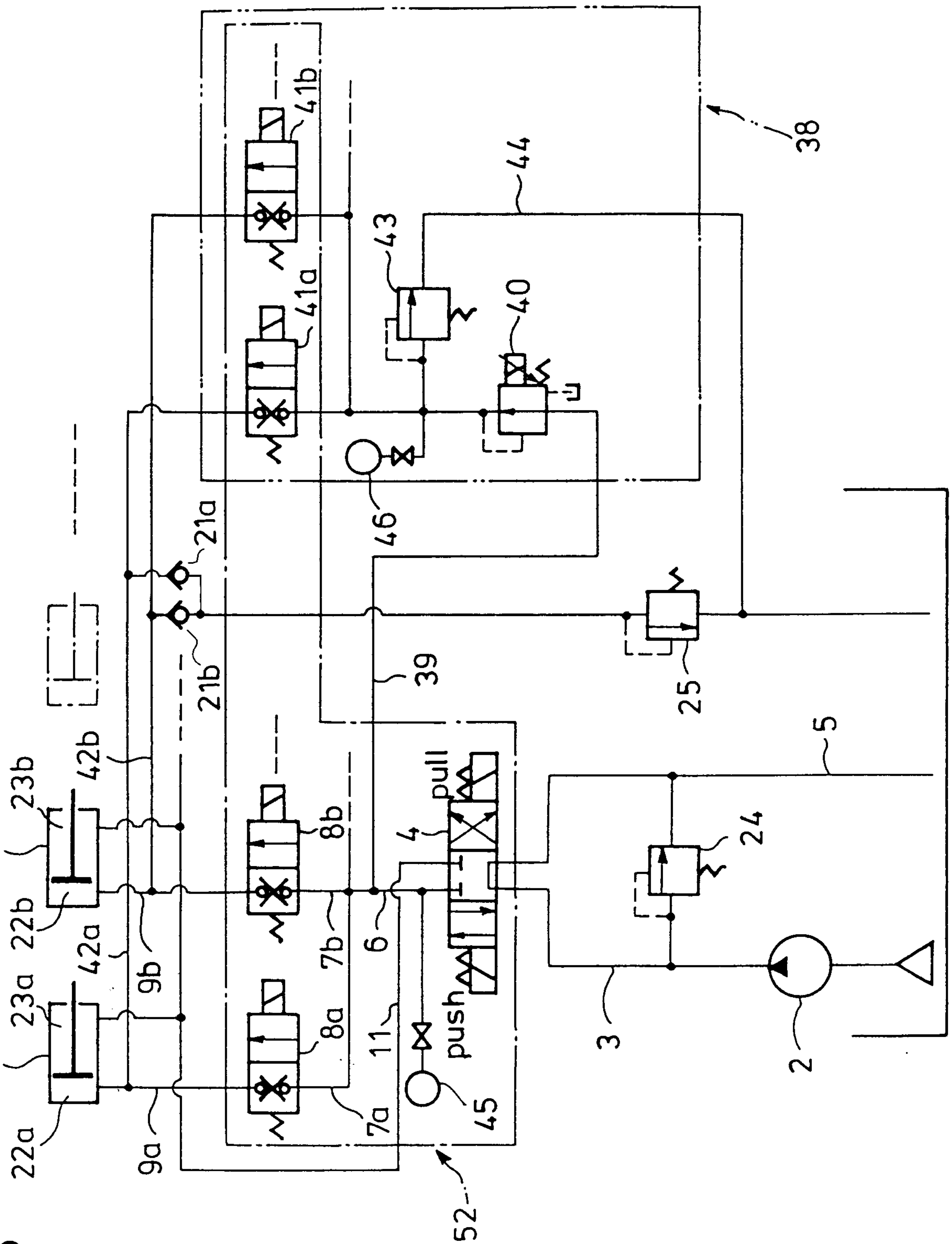
Fig.1



1
2
3
4
5
6
7a
7b
8a
8b
9a
9b
10a
10b
11
12a
12b
13
14
15
16
17a
17b
18
19a
19b
20
21a
21b
22a
22b
23a
23b
24
25
37
push
pull

Fig. 2





10a
23a
22a
10b
23b
22b
42a
42b
9a
9b
21a
21b
7a
7b
8a
8b
6
11
45
push
pull
4
52
39
41a
41b
43
40
44
46
38
25
24
5
3
2

Fig.3

Fig. 4

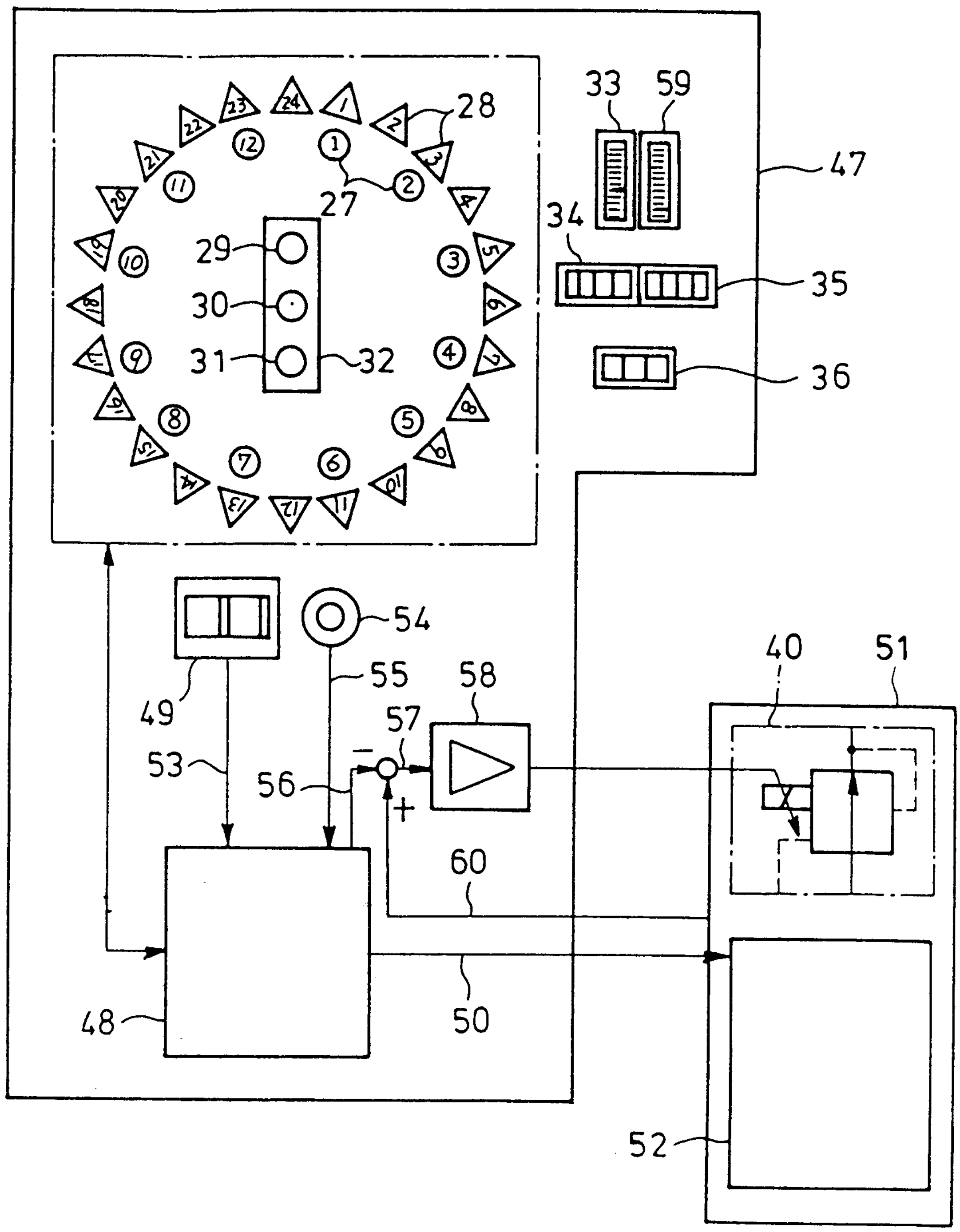

33
59
28
47
27
34
35
29
30
31
32
36
54
55
58
40
51
49
57
53
56
60
48
50
52

Fig.5(A)

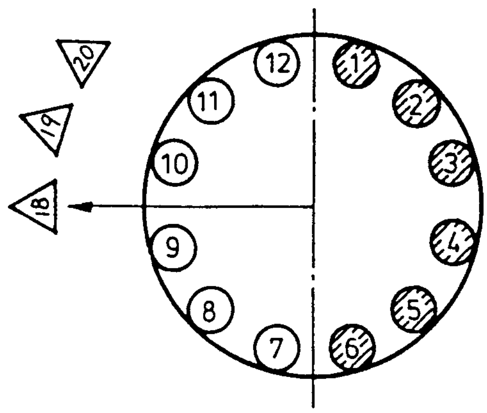


Fig.5(B)

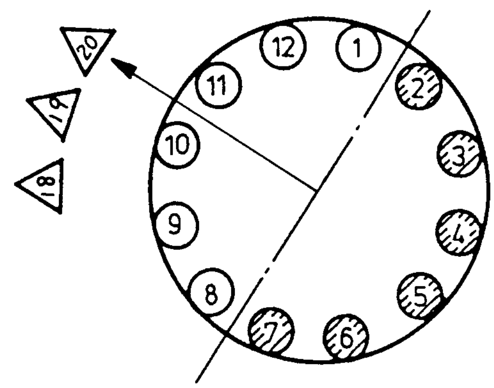
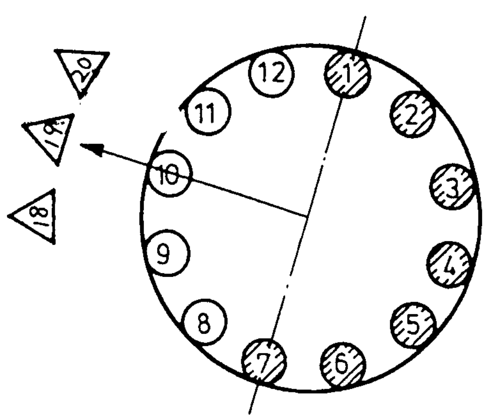


Fig.5(C)



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 30 8750

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	FR-A-2 615 241 (WESTFALIA) * Page 3, line 31 - page 4, line 20; page 10, line 21 - page 11, line 16; figure 1 * – – –	1-3	E 21 D 9/06
A	DE-A-1 409 903 (KEMPER) * Claims 4,14,15 * – – – – –	1-3	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
E 21 D

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	19 March 91	RAMPELMANN J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same catagory
A : technological background
O : non-written disclosure
P : intermediate document
T : theory or principle underlying the invention

E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document